Ornithopter Flight Stabilization

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ABSTRACT

The quasi-steady aerodynamics model and the vehicle dynamics model of ornithopter flight are explained, and numerical methods are described to capture limit cycle behavior in ornithopter flight. The Floquet method is used to determine stability in forward flight, and a linear discrete-time state-space model is developed. This is used to calculate stabilizing and disturbance-rejecting controllers.
Keywords: Ornithopter, Floquet multipliers, Stabilization

NOMENCLATURE

ϕ	=	angle of flapping oscillation
Ch	=	amplitude of flapping oscillation
Ct	=	amplitude of wing twist at the tip
?	=	frequency of flapping
t	=	time
r	=	coordinate along span of a wing
?	=	instantaneous wing twist
ϕ0	=	phase of flapping oscillation
ϕ?0	=	phase of twisting oscillation
Γ	=	circulation around the airfoil
CL	=	translational lift coefficient
CR	=	rotational lift coefficient
c(r)	=	local chord value
u	=	local section velocity parallel to chord
v	=	local section velocity normal to chord
Fv	=	viscous force
ρ	=	air density
CD(0)	=	drag coefficient at zero angle of attack
CD(π/2)	=	drag coefficient at 90° angle of attack
dFx	=	local force on the wing parallel to chord
dFy	=	local force on the wing normal to chord
mw	=	wing mass
m11, m22	=	added mass parameter
α	=	angle of attack
R	=	wing length
τ	=	airfoil moment
U	=	vehicle forward velocity
W	=	vehicle velocity normal to forward velocity
Q	=	vehicle pitch rate
Φ	=	vehicle pitch angle
g	=	gravitational constant
Fx	=	total aerodynamic force on vehicle in forward direction
Fz	=	total force on vehicle in downward normal to forward direction
m	=	vehicle mass
Iy	=	moment of inertia about pitching axis

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